2010-09

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INTRODUCTION

Team 7 developed an Agent Based Model in NetLogo 4.1 to study the impacts of the placement and size of resource dispensaries and processing centers on the successfulness of a Humanitarian Relief Mission. The model tracks the number of people in need of resources, time to receive resources, crime incidents, and population migration. The model incorporates social attributes, ethnicity, and people's resource desires.

MotIvation

As evidenced by the humanitarian disasters in Africa, Haiti, Pakistan, and Turkey, humanitarian assistance and disaster relief (HA/DR) missions continue to be in major demand. As evidenced by the examples presented above, these oftentimes lead to sociopolitical instability, and in some extreme cases, war and genocide.[9] It is well understood that a country's situation can quickly deteriorate when struck by a natural disaster of a sufficiently large magnitude. What is more difficult to prove, but has in fact happened on a number of occasions, is that humanitarian assistance missions produce unexpected effects that could have been avoided if the missions would have been planned differently. Somalia in 1990, Rwanda in 1993, East Timor in 1998, New Orleans in 2005, and Haiti in 2010 are all cases where the humanitarian assistance was either insufficient, lacked a comprehensive spectrum of operations, and eventually fueled blowbacks[1].

The majority of the work in this field focuses on optimizing the logistics to bring maximum amount of resources in the minimum amount of time to the region in question. This, however, is not always sufficient. In the aftermath of the 7.0 Richter Scale magnitude earthquake that struck Haiti in 2010 there were many accounts of looting, gun-fights, and riots due to the lack of security enforcement and resource shortages.[1,2] It is not enough to just get relief to the region it must also be distributed throughout the population in a safe and secure manner. The most common approach is to setup centers in order to provide the population with the required resources and services. The questions we ask are how should these centers be set up to best meet the needs of the people? Should there be fewer centers with greater capacity or should there be more low capacity centers? Should the centers' locations account for the characteristics of the population, e.g., can resource distribution incite ethnic violence? How does the total daily operation time affect the distribution of resources and services? And finally, how do these produce different levels of insecurity and population migration? In order to study these effects, Team 7 developed an agent-based model that attempts to capture the most pertinent elements of the problem.

Modeling

In order to develop the proper model of a HA/DR mission, one must consider the following aspects of the community in distress: population density, ethnic makeup and tensions, social attributes, resources availability and desire, crime rates, and the location and makeup of processing and dispensary centers. The model was developed in NetLogo 4.1, a free agent-based modeling and system dynamics modeling framework developed by The Center for Connected Learning and Computer-Based Modeling at Northwestern University.[10]

Population Density

Modeling every individual in the population as an agent would be infeasible from a computational standpoint, so a method for simplifying the pertinent characteristics of the population had to be devised. To confront this issue a combination of Cellular Automata and Agent Based Models were used. The environment that the model operated on was split up into 32x32 patches. These patches represented a geographical area of a given physical dimension represented in meters. Each patch contained information on the number of individuals living in this area in addition other information discussed in the following sections. The total number of people in the model is predefined and then is random distributed throughout the map. The model can be easily modified to have higher resolution—i.e., higher discretization —of the environment.

Ethnic Considerations

Not all HA/DR scenarios have a major focus on ethnic conflict. On the other hand, some HA/DR missions are a

[1] Blowback is a term used to refer to situations where unexpected and undesirable consequences occur from seemingly benign actions

direct result of, or can be affected by, ethnic tensions. For this reason the ethnic makeup and corresponding tensions of a region must be considered in order to study how conflict arises. Of particular interest to this study is: how does the placement and distribution of the centers impact ethnic tension?

A simple example of how resource placement can induce violence can be explained by Figure 1. Let's assume we have two ethnic groups (A and B). In addition assume these two groups have a history of violence , then by the placement of a resource center (denoted as a blue star) can lead to increased violence by forcing ethnic group A to travel through a region dominated by group B.

The model includes the ethnic group breakdown by percentage for each patch. In addition the model includes an inter-relationship matrix that determines how well the different ethnic groups interact. This will have an important impact when studying the crime.

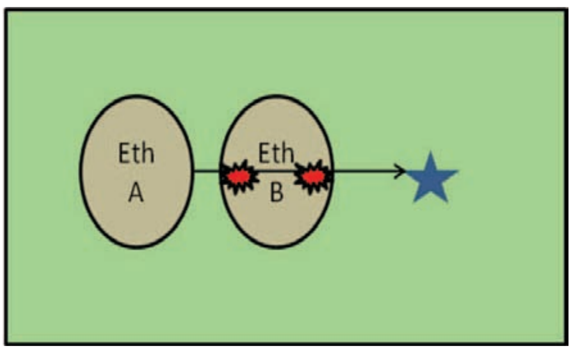

Figure 1: Example of violence induced by resource placement

Social Attributes

Social attributes help to better define the makeup of the population. This data is stored in the patch. Some examples of these attributes are: poverty rates, education rates, and employment. These metrics will play a major role in calculating crime. The social attribute data can be attained from census data.

Resource Availability vs. Desire

Every patch will contain information on the amount of resources that exist on that patch. Examples of this could be liters of water and calories of food. The patch will consume the resources at a specified rate. This will continue to change until the patch reaches the desire threshold. Every patch has a slightly different desire. If the patch reaches the desire threshold then those on the patch deem their state of resources to be insufficient and will create a gathering agent. This gathering agent will consist of a percentage of the people on the patch. The percentage is predetermined. This gathering agent will then travel to the nearest resource dispensary to acquire the desired resources and bring it back to its home patch.

Processing and Dispensing Centers

An important distinction needs to be made between a processing center and a dispensing center. A processing center is a center that the people visit to have some service done for them or to them. There is nothing physical that the people leave the center with. The people must report here to receive what is needed. Examples of this include hospitals or vaccination clinics. The demand for processing is created randomly in the model. In contrast, a dispensing center is one that gives the people a material good that can be carried back to their home. The people could either report to the center personally to receive the good or have someone retrieve the good for them. Examples of this are food, water, and tents.

Every center has a maximum throughput capacity and a limited supply. The throughput capacity is determined by the number of people that can be processed at once and the time it takes to process an individual. The throughput capacity of the resource and processing centers can, and probably will, differ greatly. For example, more time is required to treat medical needs than to hand out food. In addition, medical experts are in shorter supply than people who can hand out food. The agent will arrive at the center and get into a line. They will wait until they are processed, the center runs out of resources, or the center closes. Once this occurs the agent returns home.

Crime

Crime is an important and complicated aspect of this model. As referenced earlier, crime ran rampant in a wide variety of HA/DR missions, especially in Haiti after the 2010 earthquake. This was a result of insufficient security forces and lack of vital resources. Understanding how the placement of centers impacts the crime of the affected area is essential to produce a comprehensive and satisfactory plan for HA/DR missions.

The occurrence of crime is a result of a vast number of different factors.[3] These factors range from socioeconomic status and education to criminal punishment and reinforcing nature of crime.[3,4,5,6,7] In addition, crime rates and the sources of crime vary across different societies.[3] For a measure of impact on crime rates the reader is referred to references 3 through 7.

Due to the wide range of factors contributing to crime and the varying impacts across different societies an expandable and adaptable crime model was developed. This model is composed of two phases. The first phase is the probability of a patch to create a crime agent. The second phase takes place when the crime agent travels in a random walk until it commits a crime. A crime agent will commit a crime based on a separate probability, based on the characteristics of that agent and the patch where that agent currently is. The probability of a patch to create a crime agent is presented in Equation 1. The probability of a crime agent to commit a crime is presented in Equation 2.

Equation 1 is composed of six elements. The first is the dominating coefficient multiplying the whole equation, DN. This coefficient allows the probably to distinguish between day and night. The second part is a summation of the impact of social attributes on crime with their corresponding weightings. The third part is a measure of the desire level of the patch. If the people are without critical resources they are more likely to engage in criminal acts out of desperation. The fourth is a measure of an ethnic group's tendency towards crime. The hypothesis is that one ethnic group may be quicker to resort to crime than another. This ethnic consideration may not always be present and can be zeroed if deemed irrelevant. The fifth part is the factor that describes the reinforcing nature of crime.[4,5] The sixth, and final part is a measure of the impact on the presence of security forces.

Equation 1

$$P = DN\begin{bmatrix} \sum_{i=1}^{n} a_i \frac{(100 - SA_i)}{100} \\ + \sum_{j=1}^{m} a_{n+j} \max\left[0, 1 - \frac{RL_j}{RD_j}\right] \\ + \sum_{k=1}^{o} a_{n+m+k} Eth_k \\ + c * CC \\ - \sum_{l=1}^{e} E \frac{1}{\max\left[1, R_l^2\right]} \end{bmatrix}$$

Equation 2 is the probability a crime agent will commit a crime, and it is similar in form to Equation 1. The first significant change is the second summation term. This is a measure of the crime agents' desire for resources and the potential victims' desire for resources. The potential victim is the current patch that the crime agent is on. The next difference is in the next term. Here the ethnicity of the crime agent and the potential victim plays a role. Depending on the ethnic relationship this could increase or decrease the probability of a crime being committed. The final difference is that there is no self reinforcing nature of crime once the crime agent is produced.

Equation 2

$$P = DN\begin{bmatrix} \sum_{i=1}^{n} a_i \frac{(100 - SA_i)}{100} \\ + \sum_{j=1}^{m} a_{n+j} \left(1 - \min\left[1, \frac{RL_j}{RD_j}\right]\right) \frac{RL_v}{RD_v} \\ + E_{Et,Et} Eth_v \\ - \sum_{l=1}^{e} E \frac{1}{\max\left[1, R_l^2\right]} \end{bmatrix}$$

Migration

The final element to be modeled is migration. The premise of this portion of the model is that if people are suffering—e.g., due to crime, lack of resources or services, ethnic tensions—and there are areas with better conditions, or a promise for better conditions, they are likely to leave and move to the more promising area.

Equation 3 describes the elements that compose the calculation that determines the goodness of a given patch, Pgood. The a, b, c and d terms are multipliers for each of the terms. The term rp is a relaxation constant, if it is zero the goodness of the patches does not change from one time step to the next, if it is set to one, it will have no memory of the goodness from the prior step. The first term is the summation over the m Social Attributes of patch, e.g., education, employment, etc. The parameters CT, CGM and CM, are the counters for the number of crimes committed by crime agents from other patches on the patch, how many successful crimes crime agents from that patch have conducted in other patches, and the number of gatherers that have been mugged on that patch respectively. The parameter t is time. Pop and PopAreaRatio are the number of people residing on that patch and the ratio between total area and total population respectively. This term helps quantify overcrowding in relative terms. The final term is a measure of how many resources that patch is lacking, where (RD)i is the ith resource desired and (RP)i is the amount of that resource present. The coefficient ei is a measure of the weighing given to that resource by the population on that patch.

Equation 3

$$P_{good} = (1 - r_p) P_{good} + r_p \begin{bmatrix} \frac{a}{m} \sum_{i=1}^{m} SA_i \\ - b \frac{(CT - 4CGM - CM)}{t} \\ - c(Pop \times PopAreaRatio) \\ - d \sum_{i=1}^{n} e_i \frac{(R_D)_i - (R_P)_i}{(R_D)_i} \end{bmatrix}$$

The goodness of all the patches is calculated at every time step, and it is compared to a parameter that represents the value of the property in that patch. This parameter accounts for the fact that if people have a highly valuable property, they are more likely to remain there rather than if they have no material reason to stay.

Once a group of people in a patch decides to migrate, they look for a patch that is at least a certain amount better than their patch and has their ethnicity. Then a migration agent is created and that agent traverses to the new location.

ANALYSIS

Once the model was created, a Design of Experiments (DOE) could be executed to determine how the centers should be set up to best meet the need of the people. The first step of this process is to define the control variables of the model and the subsequent ranges.

Design Ranges

Design ranges for the center control variables can be developed from the operations used by the US Army Corps of Engineers (USACE).[8] USACE uses three different types of resource centers. They operate by loading resources into cars that pass through 4, 2, and 1 lanes of cars, respectively. This case is amenable to a domestic HA/DR operation, e.g., Hurricane Katrina. They make the assumption that each lane can process 5,000 people every 12 hours. Each car is assumed to represent 3 people and is given 1 day of supplies for each person. The centers operate for a total of 12 hours a day. With this information in addition to basic approximations, design ranges for the 10 input variables were defined and are shown in Table 1.

Variable	Lower Bound	Upper Bound
Population	50,000	200,000
Center Operation Time	8 Hr	18 Hr
Resource Limit	2,000 ppl	20,000 ppl
Dispensary Lines	1	6
Time to Dispense	20 sec	30 sec
Number Resource Centers	1	20
Supplies Dispensed	1 Day	10 Days
Number Process Centers	1	8
Processing Lines	2	10
Time to Process	5 minutes	60 minutes

Table 1: DOE Variable Ranges

Design of Experiments

The DOE selected for the analysis of the model utilized a 128 case Nested Latin Hypercube Design (NLHD) developed by Prof. Peter Qian from the University of Wisconsin plus three different variations of a 20 case Robust Screening Design (RSD). These 20 cases were scaled to span 50%, 75% and 100% of the design space, for a total of 60 cases. Each of the 188 cases was executed 20 times to obtain statistical significance.

The 128 NLHD cases allow the designer to run increasingly larger blocks which remain orthogonal, i.e., the first block has 16 cases which are orthogonal, and when the additional blocks of 16, 32, and 64 cases are included, the correlation of the aggregated design remains at a minimum value. This allowed the team to obtain results at the workshop, whereas it would not have been possible from a computational standpoint to execute the 128 cases with their 20 repetitions during the workshop. Including the RSD and NLHD cases and their 20 repetitions, Team 7 executed a total of 3,760 cases.

The RSD cases are used to validate the goodness of the regressions based on the NLHD cases. The sequentially increasing span of the RSD allows for the testing of how well the model interpolates and extrapolates to the corners of the design space. The authors extend their thanks to Tom Donnelly from JMP for providing the knowledge and the designs.

Results

The data collected from the model included resource needs, processing needs, crime rates, and migration at 6 points over three days (every 12 hours of simulation). The data was analyzed using JMP. The analysis shed light onto the question of how the centers should be set up. It was found that the number of centers was a more critical factor than their number of lines. This tells us that during HA/DR missions it is better to set up several small centers with low capacity throughout a region as opposed to few large centers with high capacity. This result is in agreement to what is to be expected, since the economies of scale of having fewer larger centers and their increased logistic efficiency cannot be currently computed by the model. Total time of operation of the centers did have an impact, however it did not have nearly as large an impact as the number of centers or total capacity did.

Future Work

Future work will focus on improving the behavior of the agents and the models for crime and migration. In addition, the team plans to develop a more intelligent method for placing the centers, allowing greater granularity in the study of the planning of HA/DR missions.

REFERENCES

[1] "Haiti Earthquake: Looting and Violence Break out - Telegraph." Telegraph.co.uk - Telegraph Online, Daily Telegraph and Sunday Telegraph - Telegraph. Daily Telegraph, 15 Jan. 2010. Web. 29 Nov. 2010. <http://www.telegraph.co.uk/news/newsvideo/6996287/Haiti-earthquake-looting-and-violence-break-out.html>.

[2] Sherwell, Philip, and Patrick Sawer. "Haiti Earthquake: Looting and Gun-fights Break out - Telegraph." Telegraph.co.uk - Telegraph Online, Daily Telegraph and Sunday Telegraph - Telegraph. Daily Telegraph, 16 Jan. 2010. Web. 29 Nov. 2010. <http://www.telegraph.co.uk/news/worldnews/centralamericaandthecaribbean/haiti/7005554/Haiti-earthquake-looting-and-gun-fights-break-out.html>.

[3] Malleson, Nick, Andrew Evans, and Tony Jenkins. "An Agent-based Model of Burglary." Environment and Planning B: Planning and Design 36 (2009): 1103-123. Print.

[4] Schrag, Joel, and Suzanne Scotchmer. "The Self-reinforcing Nature of Crime." International Review of Law and Economics 17.3 (1997): 325-35. Print.

[5] Buonanno, Paolo, and Daniel Montolio. "Identifying the Socio-economic and Demographic Determinants of Crime across Spanish Provinces." International Review of Law and Economics 28.2 (2008): 89-97. Print.

[6] Scorzafave, Luiz Guilherme, and Milena Karla Soares. "Income Inequality and Pecuniary Crimes." Economics Letters 104.1 (2009): 40-42. Print.

[7] Pablo, Fajnzylber, Daniel Lederman, and Norman Loayza. "What Causes Violent Crime?" European Economic Review 46 (2002): 1323-357. Print.

[8] "LEOP Planning – Appendix 4 to Annex O" State of Missouri - State Emergency Management Agency. Web. 04 June 2010. <http://sema.dps.mo.gov/Planning /LEOPPlanning.htm>.

[9] Diamond, Jared. “Collapse: Why Societies Choose to Fail or Succeed.” New York, NY: Viking Press. 2005.

[10] Wilensky, Uri. “NetLogo,” Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL. 1999. <http://ccl.northwestern.edu/netlogo/>.